R&D Studies for the sPHENIX Time Projection Chamber

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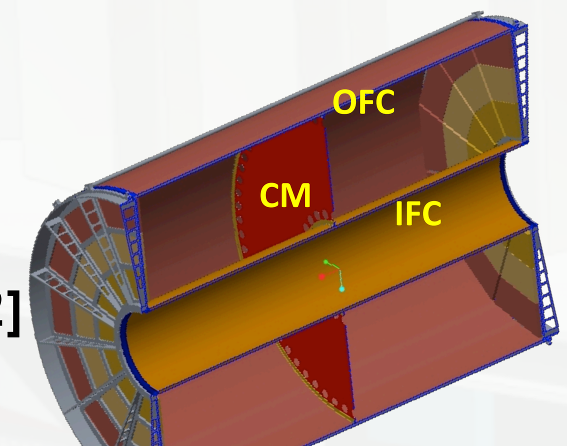
Abstract

The proposed sPHENIX detector design is focused mainly on a physics program of precise upsilon spectroscopy and jet measurements, leading to a requirement for high tracking efficiency and excellent momentum resolution. A time projection chamber (TPC) is proposed as the outer tracking detector for sPHENIX, which has a rapidity coverage of $|\eta|$<1.1 and full azimuthal coverage. The sPHENIX TPC design has to be optimized for operation in the high rate, high charged particle multiplicity environment that is anticipated at RHIC in 2022. In this presentation, we show the results of R&D, and describe the ongoing efforts to optimize the design of the sPHENIX TPC.

sPHENIX Time Projection Chamber

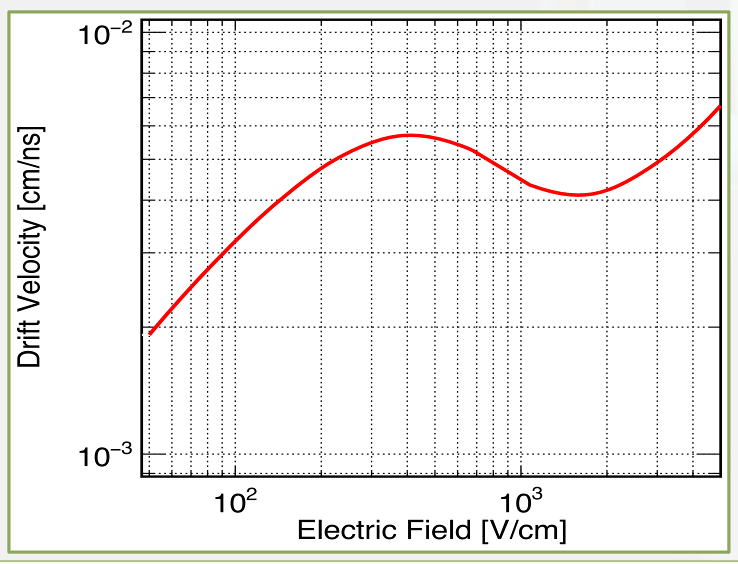
⌘ Coverage

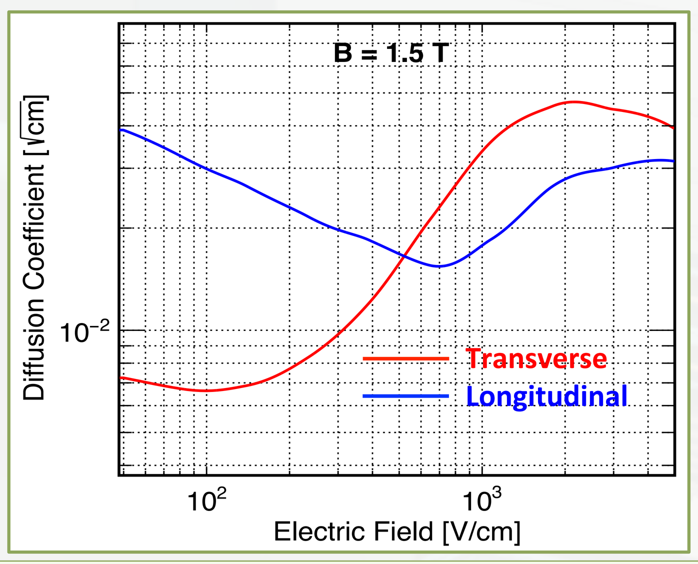
- 20 cm < r < 78 cm (~10 cm left for Future Upgrade)
- |η| <1.1 (2.11 meter of full length)
- Full azimuthal coverage



⌘ Ne based Gas mixture Ne + CF_4 + iC_4H_{10} [95:3:2]

- Dominantly Neon ⇨ Low Space Charge
- Low diffusion ⇨ Better Resolution
- Plateau in v_{drift} ⇨ Stability @ 400 V/cm





Electron Drift Velocity and gas Diffusion Coefficients for Ne + CF_4 + iC_4H_{10} [95:3:2] at NTP

⌘ Quad GEM Based Readout for Low Ion-back-flow

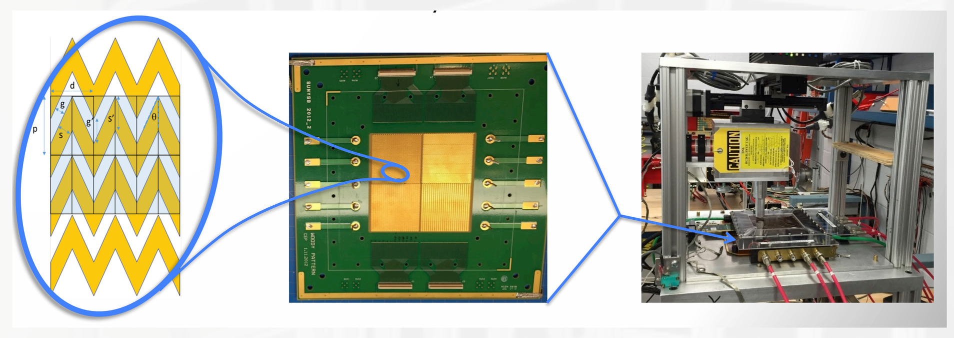
Chevron Pad Readouts

⌘ Optimize resolution:

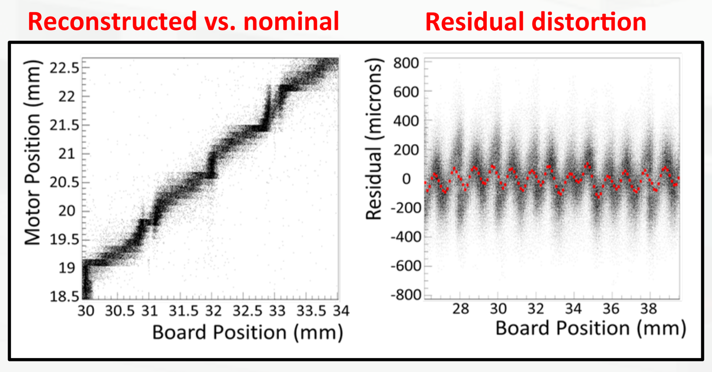
More sharing – More accuracy
Less sharing – Less occupancy

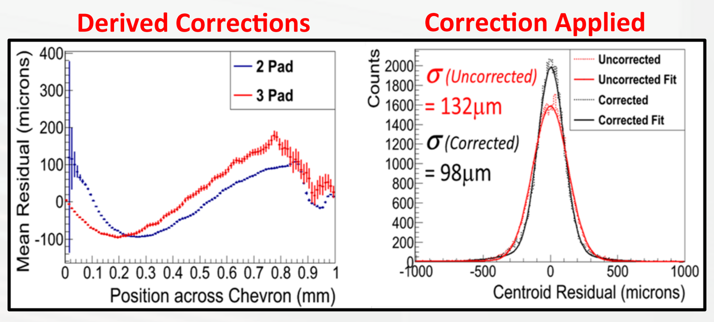
⌘ Goal:

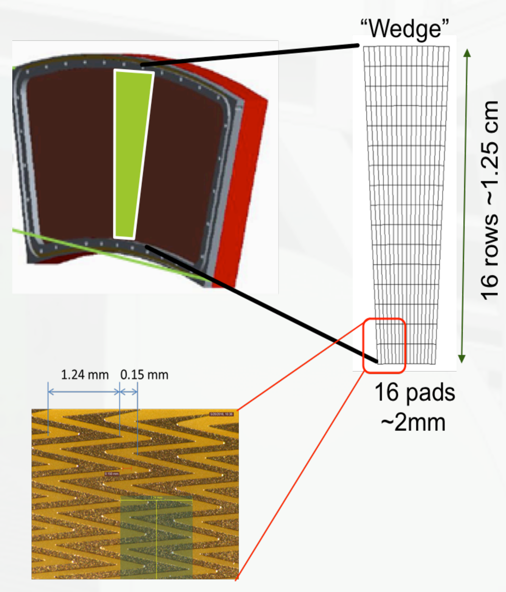
100 μm resolution with 2mm pad structure & Linearity across the structure



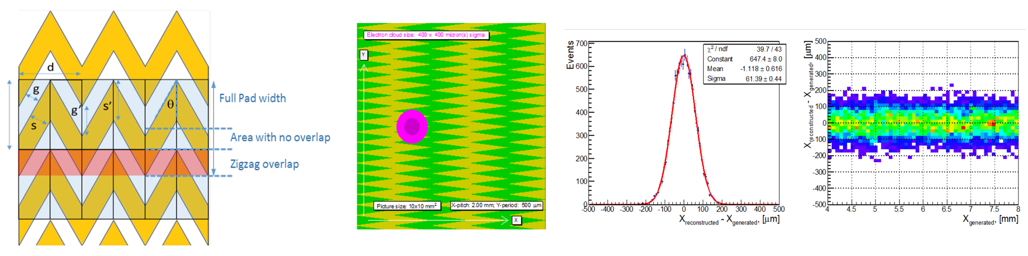
Chevron patterns guided by simulation | Manufactured for testing in the lab condition | X-Y scan facility with collimated X ray source







- Module anodes segmented into 16x16 pad "wedges".
- Pads average 2mmx 1.25 cm in size.
- Individual pads segmented as Chevron.
- Each FEE card supports a single wedge.



Further optimized 4-parameters for best resolution using simulation

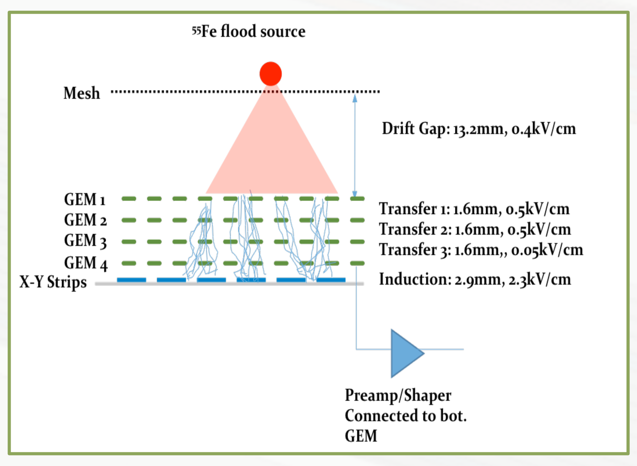
- High resolution (<100um) with relatively large pads (2x10mm)
- Minimum differential nonlinearity
- Maximize overlap of adjacent pads
- Minimize gap between adjacent pads

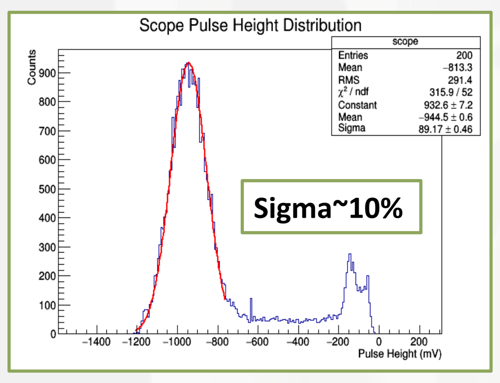
Manufacturing imposes very strong constraints on design

Gas Properties Measurements

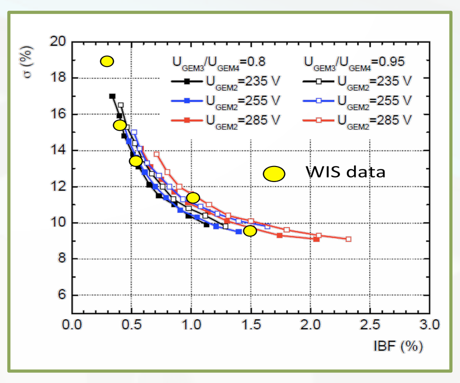
Set-Up

- Use Ne2K gas [Ne-CF4-iC4H10/95:3:2]
  Flow = 1.4 slpm [high purity]
  Press = ~1 atm. [low impedance],
  Temp = 22 ^{0}C
- 4-GEM stack of CERN Cu 4-way segmented foils [pitch-inner/outer hole : 140-50/70 μm]
- Used ^{55}Fe flood source, no collimation
- Ion backflow measurements reproduced ALICE results
- Energy resolution gets worse at lower IBF => still need to be optimized

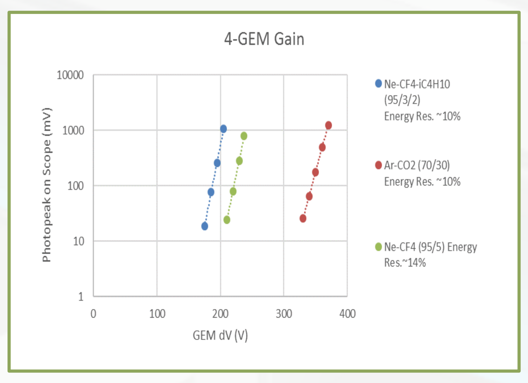




Energy Resolution observed is ~10% (Sigma)



Ion back flow measurements are reproduced for Ne+CO2+N2



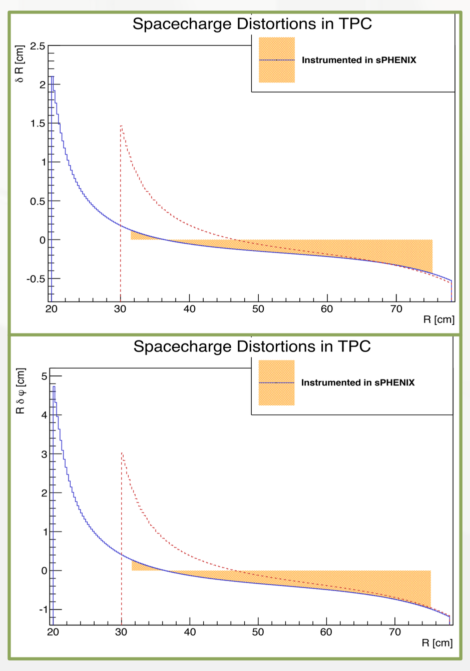
High Gain at lowed GEM Voltages with Ne2K gas

Space Charge Distortion Simulations

A fundamental limit to the application of Time Projection Chambers (TPCs) in high-rate experiments is the accumulation of slowly drifting ions in the active gas volume, which compromises the homogeneity of the drift field and hence the detector resolution.

IBF has been implemented in simulation as:

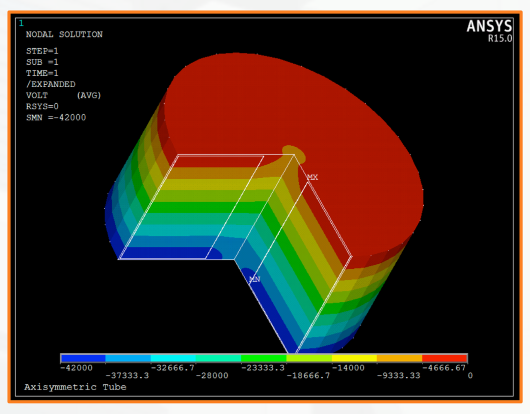
- A smear proportional to distortions
- A shift proportional to distortions



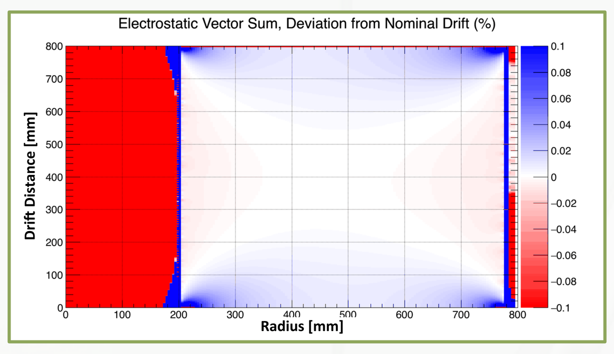
The bulk of the space charge accumulates at the inner radius of the detector volume (at 20cm), thereby minimally affecting the instrumented region from r = 32-78cm.

Mechanical Tolerance and Electric Field Distortions

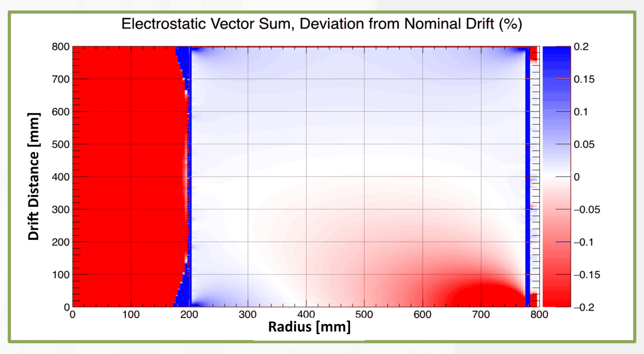
⌘ Unique feature of the field cage is its internal potential defining system designed to provide a highly uniform electric field with small radial distortions.



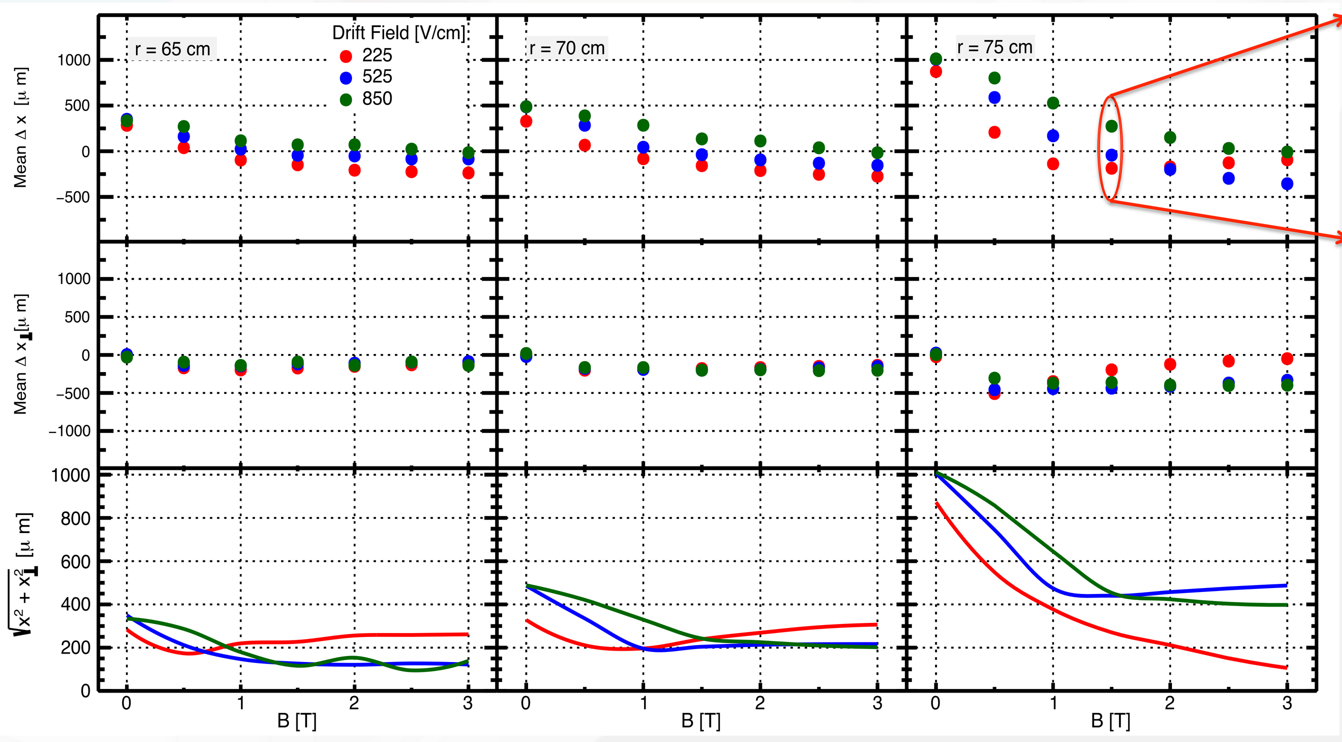
Equipotential Contours in ANSYS solved for sPHENIX TPC Geometry



Electric Field Distortions [%] for Ideal TPC Geometry



Electric Field Distortions [%] after Tilting the Central Membrane



Zero Crossing for sPHENIX TPC => Forces Balance if

$$\frac{E}{v_d} = B \times \frac{\cos\gamma}{\cos\alpha}$$

Similar Studies are done for:

- Module tilt
- Membrane tilt
- Shifted field cage
- Rotated field cage
- Resistor tolerance

Initial results seem to RELAX our mechanical design constraints.

Strong magnetic fields guide the electrons and hide electric field imperfections!

Distorted Field Maps are imported to Garfield++ with the Magnetic Field (1.5 T) after tilting the Central Membrane to study the Errors in Electron's Position in Ne2K Gas near the Outer Field Cage

For Mechanical and Electronics R&D updates see posters by K. Dehmelt and T. Sakaguchi

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